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Design of a

Reinforced Concrete Dairy Barn

Architectural Engineering

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# DESIGN OF A RE- INFORCED CONCRETE DAIRY BARN

BY

JOHN TYNDALL RUSSELL

## THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

ARCHITECTURAL ENGINEERING

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COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE 1911



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June 1, 1911

190X

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

John Tyndall Russell

ENTITLED      Design of a Reinforced Concrete Dairy Barn

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF      Bachelor of Science in

Architectural Engineering

James M. White  
Instructor in Charge

APPROVED:

*Frederick M. Waugh*

HEAD OF DEPARTMENT OF *Architecture*



## INTRODUCTION

The circular dairy barn is a rather unusual type of barn, but a study of its advantages shows it to be the most economical and convenient form under ordinary conditions. The difficulty with most round dairy barns that have been built is that they do not have a self-supporting roof, and consequently lose many of the advantages of a properly constructed round barn. This is the principal reason why round barns have not become more popular. A straight roof necessarily requires many supports in the barn below. These are both costly and inconvenient, and make the roof no stronger than a dome-shaped, self-supporting roof which nearly doubles the capacity of the mow. This large storage capacity of the round barn is an important feature, especially so when there are no columns or girders to obstruct the handling of the hay. The hay is stored in the mow by means of a carrier which travels around a circular track supported from the roof, midway between the silo and the outside wall. A large saving in labor is accomplished in this manner, for the hay can be dropped at any point desired and requires very little placing. By no means the least important feature of the round barn is the arrangement and construction of the silo. A silo is practically a necessity in a dairy barn situated in a locality where silage is available. Good pasture is the ideal food for the dairy cow. In this part of the country green pasture is not available



for more than six months of the year. For the other six months a substitute must be used. Corn silage has been found to be the best and cheapest substitute for pasturage. The corn for the silo should not be cut before the middle of September when the corn is ripe. It is well to use a silage cutter of large capacity as much less labor is required in feeding it. The silage is fed into the silo by means of a blower attached to the cutter. In the circular dairy barn the silo is situated in the center, and there are doors in the silo from which the silage is fed into a silage chute attached to the outside silo wall. When there is but one row of cows the feed alley is in the center around the silo; this makes it very convenient in feeding and is a saving in labor. When there are two rows of cows, they may be either headed or tailed together. If they are headed together, only one feed alley is required, while if they are tailed together two feed alleys and one cleaning alley are necessary. It is often convenient, when there are two rows of cows, to have them tailed together, having a wide cleaning alley, broad enough for a large wagon to drive through; it facilitates the operation of cleaning and bedding the stalls.

The question as to whether there shall be one or two rows of cows is dependent on the number of cows to be accommodated. About the minimum number of cows that can be put in a single row is 36; this is with an 18 foot silo. The minimum number that can be placed in two rows with an 18 foot silo is about 75. Here is where the round barn is at fault; it is adaptable for herds of from 35 to 50, using one row of



cows, and for herds of from 75 up to 125 using two rows, but for a herd numbering between 50 and 75, it is doubtful economy to use the round type of barn, because to place, say, 65 cows in one row, the stanchion diameter would have to be at least 65 feet. This would leave a great quantity of waste space in the center; the feed alley would be about 23 feet wide, which is very excessive. The problem taken up in this thesis is the design of a circular dairy barn of reinforced concrete. It is of monolithic construction throughout including the silo and roof. The barn is designed for a herd of 50 cows which is about the maximum that can be economically placed in a single row in this type of barn. The silo is surmounted by a water tank of sufficient capacity to supply the herd for about two weeks. Adjoining the barn and located under the drive leading up to the mow floor is the milk room. This arrangement is practical for it is at present in use at the dairy barn of the Agricultural Experiment Station of the University of Illinois.



### The Water Tank

While it is true that the underground tank is gaining in favor over the elevated tank, there are many who still cling to the old type of overhead tank. Where engine or electric power is not available, the overhead tank is the only one that can be used. The chief objections to the elevated tank are the liability of the water freezing in cold weather and the tendency of the water becoming warm and stagnant in hot weather.

In the present problem it is believed that both of these objections are overcome. The tank selected is of 200 barrels capacity, being 12 feet in diameter and 8 feet deep. The silo is 18 feet in diameter and is roofed with a flat slab which forms the bottom of the tank. The silo walls are carried up beyond the height of the tank and roofed over, thus enclosing the tank completely. The vent flues open into the tank house and will help keep the water from freezing in cold weather; in hot weather the water is not liable to get very warm for it is not exposed to the direct rays of the sun like the ordinary type of elevated tank.

In designing the tank walls the steel was assumed to take all the tension developed by the lateral pressure of the water. The radial pressure at the bottom equals  $8 \times 62\frac{1}{2}$  = 500 pounds per square foot. From mechanics, we have the relation that  $\frac{S}{R} = \frac{d}{2t}$

where

$S$  = allowable stress in steel,



R = radial pressure of water,

d = diameter of tank,

t = thickness of steel.

S = 10,000 pounds per sq. in.

R =  $500 \div 144 = 3.47$  pounds per sq. in.

d =  $12 \times 12 = 144$  inches.

$$t = \frac{dR}{2S} = \frac{144 \times 3.47}{2 \times 10,000} = 0.0249 \text{ inches}$$

Amount of steel per foot of height at bottom of wall =  $12 \times 0.0249 = 0.299$  sq. in. To take up this lateral tension, horizontal bands of steel will be run around the tank.

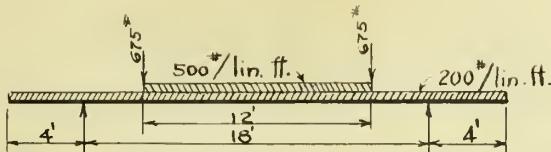
7/16 inch round rods, 6 inches on center, give a steel area of 0.30 square inches per foot. At the top of the tank very little will be required so the spacing there will only have to be about 12 inches center to center. The spacing will be graduated from 12 inches at the top to 6 inches at the bottom. It would be well to place vertical rods about every 16 or 18 inches around the tank.

In designing the slab forming the floor of the tank it was necessary to make an assumption regarding the proper moment to use. The slab was designed as a beam continuous over the supports, the supports being the walls of the silo. By making the slab continuous over the supports, additional strength was given to the roof at the portion adjoining the silo. A bending moment of  $-\frac{Wl}{20}$  was assumed, this being considered as amply sufficient for a beam of this character. The weight of the water produced a uniform load of 500 pounds per



square foot on the slab and the tank wall gave a concentrated load of 675 pounds per lineal foot. Considering then a beam one foot wide extending across the silo, it would be loaded as follows:

Fig. 1



$$\text{Weight beam} = 2 \times 675 + 12 \times 500 = 7350\#.$$

$$\text{Weight of beam} = 200\# \text{ per lineal foot.}$$

$$\text{Total weight} = 7350 + 26 \times 200 = 12,550.$$

$$\text{Moment} = \frac{Wl}{20} = \frac{12,550 \times 18}{20} \times 12 = 135,540 \text{ lb. in.}$$

$$\frac{M}{R} = bd^2$$

Where

M = moment,

R = coefficient of resistance.

R = 72 for working stresses of 16,000<sup>#</sup> per sq. in. in steel; and 500<sup>#</sup> per sq. in. in concrete.

d = distance from top of beam to center of steel.

Considering a beam 12 inches wide

$$d^2 = \frac{135,540}{72 \times 12} = 156.8$$

$$d = 12.5$$

Adding 2 inches to cover the steel,

$$\text{Total depth of slab} = 12.5 + 2 = 14.5 \text{ inches.}$$

Amount of steel needed = pbd =

p = percentage of steel,

b = width of beam,

d = effective depth



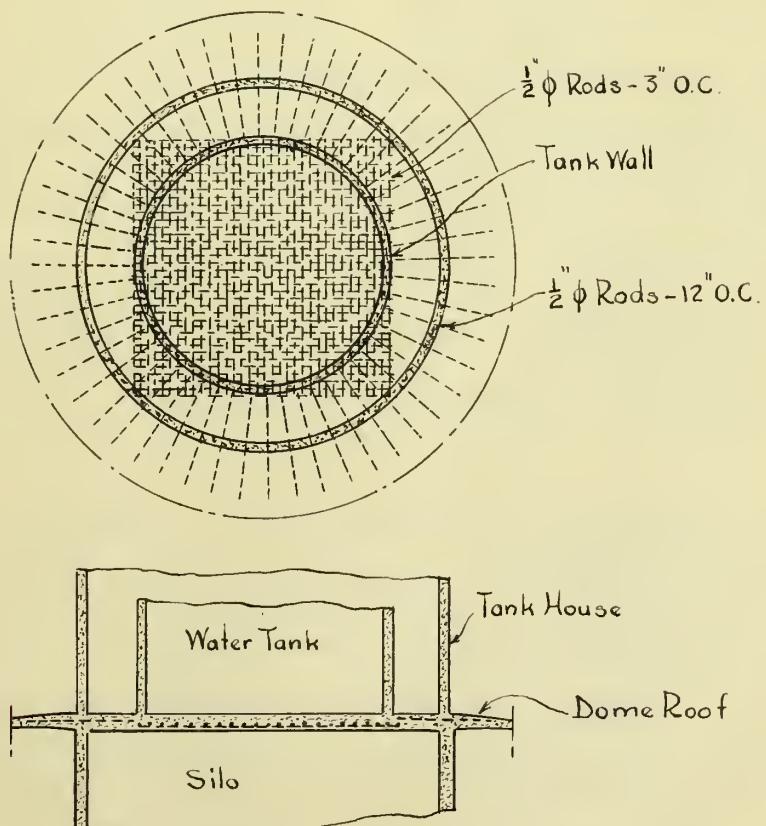
A steel percentage of 0.5% will be used.

$$A = .005 \times 12 \times 12.5 = 0.75 \text{ sq. in.}$$

1/2" rods 3" on center give a steel area of 0.78 sq. in.

This reinforcement will be run in two directions at right angles to each other. It will extend only to the outer edges of the tank. To take care of the negative bending moment over the silo wall, 1/2 inch round rods spaced about 12 inches on center will be used. They will be placed radially and will extend about 2 feet on both sides of the silo wall as shown in figure 2

Fig. 2





### The Silo.

In building a silo of concrete or any other material it is essential that the inside walls be perfectly smooth as well as air tight. These requirements are more readily obtained in a concrete silo than in one of any other type. While a concrete silo costs more to build than the ordinary King or Gurley silo, both of which are of frame construction, it lasts longer and, if properly constructed, retains its efficiency indefinitely.

The quality of silage improves as the depth increases, due to the weight above. The silage is thus compressed, which condition excludes the air from the silage and fosters good preservation. By building a deep silo a greater percentage of good silage is obtained which is, of course, a matter of economy. Good practice seems to dictate that the depth should at least be 30 feet. The footing of the silo should extend below the frost line to prevent heaving of the ground.

The capacity of a silo varies as the square of the diameter, while the wall surface varies directly as the diameter. This means that as far as capacity is concerned, the silo should be of as large a diameter as possible. But there are other limiting factors involved. When silage is left exposed to the air for a short time, more than a day, it spoils. Enough must be removed daily so that it will keep fresh. In well settled silage the air does not penetrate



much more than an inch, and if 1-1/2 to 2 inches are fed from the surface daily the silage will remain fresh. It has been noticed also that air penetrates into loose dry silage farther than it does into that which is moist and compact. Thus it is seen that under some circumstances an inch might be sufficient, but in order to have fresh silage under all conditions, the silo should be of such size that approximately 2 inches will be fed from the surface daily.

The size of the silo is governed by the number of cows in the herd and the amount of silage to be fed each cow.

About forty pounds of silage per cow per day is the maximum ration. A herd of 50 cows would consume  $50 \times 40 = 2000$  pounds, or one ton daily. Assuming that they would require this feed for 200 days in the year, it is seen that a silo of 200 ton capacity would be required; it is usual, however, to allow about 1/8 for waste, so one with a capacity of about 225 tons will be used. In table I, are shown the capacities of different sizes of silos. It is taken from the Iowa State College Bulletin of July 1909, and is the result of observations made by Professor F. H. King of the University of Wisconsin. From this table it is seen that a silo 18' x 40' with a capacity of 229 tons will be of about the proper size.

Professor King has also made investigations of the pressure of the silage against the silo wall. He found in these experiments that the pressure of silage upon the silo wall increased with the depth and was equal to 11 pounds per square foot of each foot in depth. Thus it is seen that the



10-  
TABLE I  
CAPACITY OF ROUND SILOS

Inside Diameter	Height-Feet	Capacity Tons	Acreage to fill 15 tons to the acre	Amount that should be fed daily-Pounds
10	28	42	2.8	525
10	30	47	3.0	525
10	32	51	3.4	515
10	34	56	3.7	525
10	38	65	4.3	525
10	40	70	4.6	525
12	28	61	4.1	755
12	30	67	4.5	755
12	32	74	5.0	755
12	34	80	5.3	755
12	36	87	5.8	755
12	38	94	6.4	755
12	40	101	7.3	755
14	28	83	5.5	1030
14	30	91	6.1	1030
14	32	100	6.7	1030
14	34	109	7.2	1030
14	36	118	7.9	1030
14	38	128	8.5	1030
14	40	138	9.2	1030
16	28	108	7.2	1340
16	30	119	8.2	1340
16	32	131	8.7	1340
16	34	143	9.5	1340
16	36	155	10.3	1340
16	38	167	11.1	1340
16	40	180	12.0	1340
18	30	151	10.0	1700
18	32	166	11.0	1700
18	34	181	12.0	1700
18	36	196	13.2	1700
18	38	212	14.1	1700
18	40	229	15.3	1700
18	42	246	16.4	1700
18	44	264	17.6	1700
18	46	282	18.8	1700
20	30	187	12.5	2100
20	32	205	13.6	2100
20	34	225	15.0	2100
20	36	243	16.2	2100
20	40	281	18.8	2100
20	42	300	20.0	2100
20	44	320	21.3	2100
20	46	340	22.6	2100
20	48	361	24.0	2100
20	50	382	25.5	2100



pressure on the silo wall acts like water pressure in a tank. At a depth of 40 feet the pressure acting on the wall would be equal to  $40 \times 11 = 440$  pounds per square foot. If it is assumed that the steel takes all the tension, the same formula is applicable here as was used in the design of the steel in the water tank.

$$\frac{S}{R} = \frac{d}{2t} \quad t = \frac{dR}{2S}$$

$$t = \frac{18 \times 12 \times (440 \div 144)}{2 \times 16,000} = .0206 \text{ inches.}$$

Area of steel per foot of depth =  $12 \times .0206 = .247$   
sq.in.

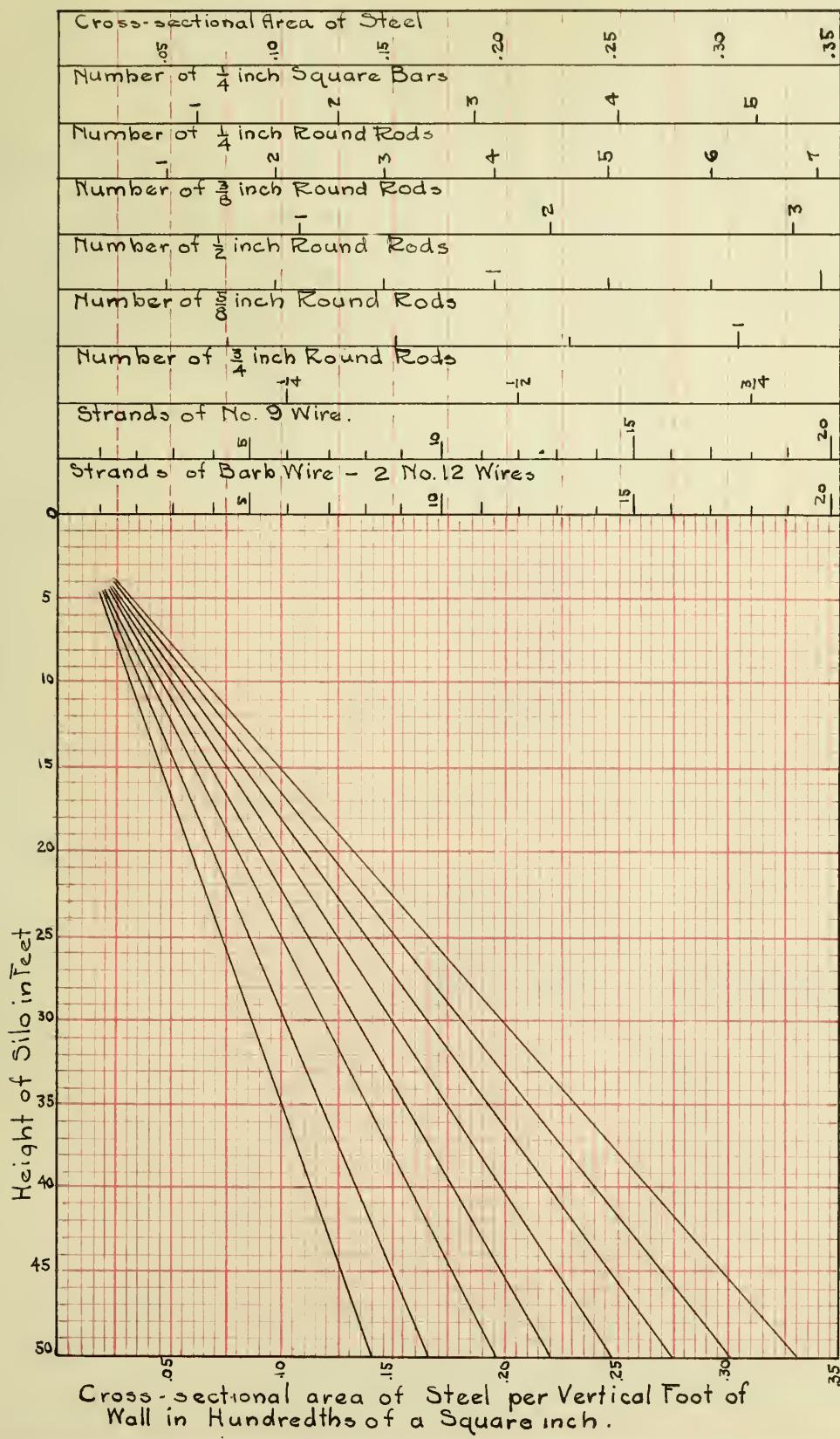
$3/8"$  rods 6" on center give a steel area = .24 sq.in

Table II gives the amount of reinforcing necessary for different sizes of silos. It is taken from the Iowa State College Bulletin of July 1909. It is based on a tensile stress of 20,000 pounds per square inch in the steel. This is a little higher than the average of good practice. 16,000 pounds per square inch is the usual working strength of steel. perhaps it is safe enough to use 20,000 pounds per square inch, for the concrete will undoubtedly take up some of the stress.

At a depth of 20 feet the stress is  $20 \times 11 = 220$  pounds per square foot, and the spacing will have to be only every 12 inches. The spacing will be graduated between these points. Some vertical reinforcement for concrete is generally recommended, although if the horizontal reinforcement



TABLE 2  
PLATE SHOWING AMOUNT OF  
HORIZONTAL REINFORCEMENT REQUIRED IN ROUND SILOS





is not spaced too far apart, it is of doubtful importance as there are no stresses to be overcome in that direction except direct compression, which is taken care of by the concrete itself. 3/8 inch rods spaced about every 2 feet are sufficient for the vertical reinforcement. This absence of vertical reinforcement does not hold for the door openings, which should be carefully and thoroughly reinforced. Figure 3 shows a method of reinforcing around the silo door recommended in the Concrete Review of March-April 1909.

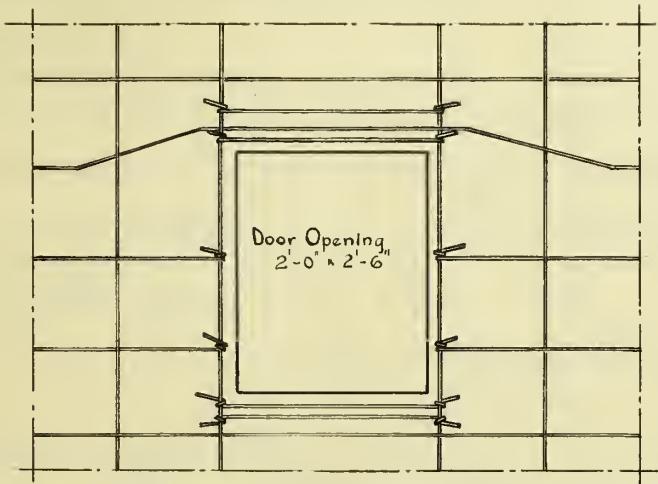


Figure 3.

Figure 4 shows the location of the door and silage chute.

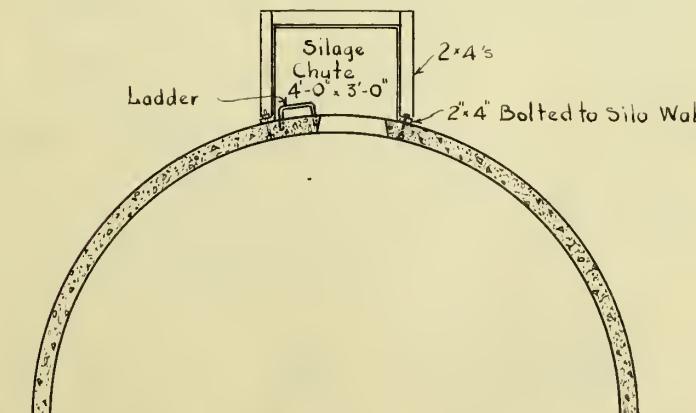


Figure 4.

The ordinary reinforced concrete silo has walls about 6 inches thick. Before adopting this size wall, it will be necessary



to investigate the stresses caused by the weight of the water, tank, and floor slab. These weights are as follows:

Water	56,500 pounds
Wall of tank - 9' high, 12' in diameter, 6" thick	26,500 "
Floor Slab - 14" thick, 18' diameter	44,250 "
Wall and roof of tank house, 4" thick	<u>38,200</u> "
Total	165,450 "

Assume 6 inch wall.

Sectional area of silo =  $58.7 \times .5 = 29.35$  square feet.

Volume of concrete in silo  $40 \times 29.35 = 1174$  cubic feet.

Weight of silo (150#/ cu. ft.) =  $1174 \times 150 = 176,100$  lbs.

Weight of tank house, roof, water, etc. = 165,450

Total weight at bottom 341,550 lbs.

Area of base = 29.35 square feet.

Unit pressure at base =  $\frac{341,550}{29.35} = 11,630$  lbs./ sq. ft.

In addition to the direct dead load of concrete at the bottom, there will be an additional vertical stress caused by the arching effect of the silage. In Ketchum's Grain Elevators and Bins, he gives a formula for computing the stresses caused in this manner, viz:

$$V = \frac{WR}{Ku} \left( 1 - e^{-\frac{Ku H}{2}} \right)$$

where

$V$  = vertical unit stress,

$W$  = weight per unit volume of material,

$R$  = ratio of area to circumference.



e = Naperian base.

h = Height of material.

u = coefficient of friction of material on walls  
of bin.

K is a constant, given by

$$K = \frac{L}{V}, \text{ where } L \text{ is lateral pressure of}$$

material and V is the vertical pressure. K and u' are values that can be obtained only from experiment. For the corn silage values of K = .67 and u' = .425 were used, these being the values given by Ketchum for wheat. There is no record of any tests made to determine these values for corn silage.

Substituting in the formula the following values.

$$u = 40,$$

$$R = \frac{254.3}{56.5} = 4.5$$

$$u' = .425$$

$$K = .67,$$

$$h = 40,$$

$$V = \frac{40 \times 4.5}{56.5} (1 - e^{-2.53}) = 581 \text{ lbs. sq. ft.}$$

Unit pressure at base = 11,630 lbs. sq. ft.

Total unit pressure = 11,630 + 581 = 12,211 lbs. sq. ft.

Total unit pressure =  $\frac{12221}{144} = 85.0 \text{ lbs. sq. in.}$

Allowable pressure = 500 lbs. per sq. inch.

It is seen that a 6 inch wall is of more than ample thickness for the load carried, but as it is not common to make silo walls of reinforced concrete less than six inches thick, the present design will be governed accordingly.



### The Roof.

In order to secure the full advantages of this type of barn it is essential that the roof be self-supporting so that there will be no posts or girders to interfere with the rapid placing and removal of the hay. Using reinforced concrete construction, there is practically only one method of building such a roof; that is the dome type. It may seem as though this form of roof is not adaptable to this problem owing to the silo and tank house in the center, but, as domes are often built with a hole or lantern in the top, it is evident that a similar treatment of the roof may be adopted in the present case. In the ordinary type of dome the weight of the lantern is carried by the roof; in this problem, however, the weights of the tank, water, and tank house were assumed as being carried directly by the silo walls, the dome being considered as continuous and unsupported in the center.

It is not intended to go into the theory of the dome here. A brief description of the method used in getting the stresses, however, may not be out of place. A thickness of 4 inches at the crown and 8 inches at the base was selected. Theoretically the thickness could be as thin as desired so long as the stress fell in the middle third of the section. A rise of about 10 feet was desired in the dome in order that as large a mow as possible could be secured. A radius of 81 feet fulfilled this condition and was adopted. At any point in a dome three stresses act, the weight, the meridional thrust, which acts downward, and is always compressive, and



the horizontal ring stress which is compression at the crown and tension at the base, from which it is seen that there must be a section above which the horizontal stresses are compressive and below which they are tensile. Horizontal planes one foot apart were passed and the stresses acting at these sections determined. The weights of each portion of the dome cut by the horizontal planes were laid off on the load line. The meridional thrusts were assumed as acting perpendicular to the radii at the points considered. In the force diagram, the meridional thrust is represented by a line drawn through the vertex parallel to the normal to the radius at the given point. The ring stress is represented by the horizontal difference between two successive meridional thrusts. For example the stress at point (1) are the weight (0-1), the meridional thrust (0-1') and the horizontal ring stress (1-1'). At point (2) the ring stress will be the horizontal distance (2' - x).

There is a thrust of 90,000 pounds developed at the outside wall of the barn. The most convenient way to take care of this stress <sup>is</sup> by hoops or rows of steel along the top of the wall.

$$\text{Amount of steel required} = \frac{90000}{16000} = 5.63 \text{ sq. in.}$$

Six 1" square rods give an area of 6 square inches. These rods could be used in lengths of 18 feet, breaking joints every 3 feet so that there would not be more than one joint at any one section.



Table III.

Point	Thick. of Shell in.	Avg. T in.	Avg. T feet.	Rau			Raut	$\Sigma$ raut
				$r = 81.05$	$a = 1.0$	$u = 150$		
0	4.00		4.20	0.350	12,158	4255	4255	
1	4.41		4.49	0.374	12,158	4547	8802	
2	4.57		4.63	0.386	12,158	4693	13495	
3	4.70		4.77	0.397	12,158	4827	18322	
4	4.84		4.90	0.408	12,158	4960	23282	
5	4.95		4.98	0.415	12,158	5046	28328	
6	5.02		5.05	0.421	12,158	5118	33446	
7	5.09		5.12	0.426	12,158	5179	38626	
8	5.16		5.19	0.431	12,158	5240	43866	
9	5.22		5.25	0.436	12,158	5301	49167	
10	5.28							

Thickness at top = 4.2" = 3.5'.

Thickness at bottom = 7.8" = .65'

Average thickness =  $\frac{.35 + .65}{2} = .50$

Total  $\Sigma$  raut = 81(12158) .50 = 492,400<sup>7</sup>



Table IV.

Point	Radius at Horiz. Sections	R Times Thickness	Total Merid. Thrust	Merid. Thrust #/sq.ft.	Merid. Thrust #/sq.in.
1	12.9	4.52	26340	5827	40.4
2	18.1	6.77	39470	5830	40.4
3	22.1	8.53	49800	5838	40.5
4	25.3	10.04	58670	5845	40.6
5	28.1	11.47	67200	5860	40.7
6	30.8	12.78	75000	5870	40.8
7	33.1	13.94	82200	5900	40.9
8	35.2	15.00	88950	5930	41.2
9	37.2	16.03	95700	5970	41.5
10	39.0	17.00	102600	6035	41.9

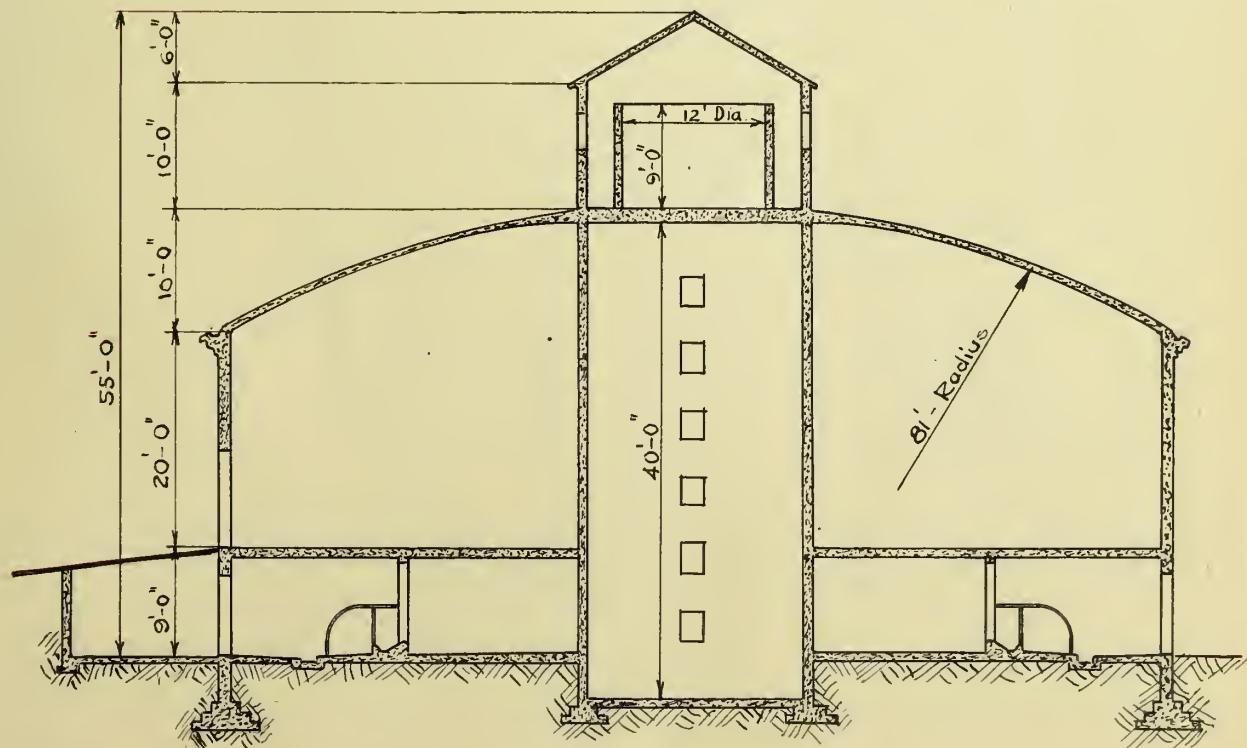
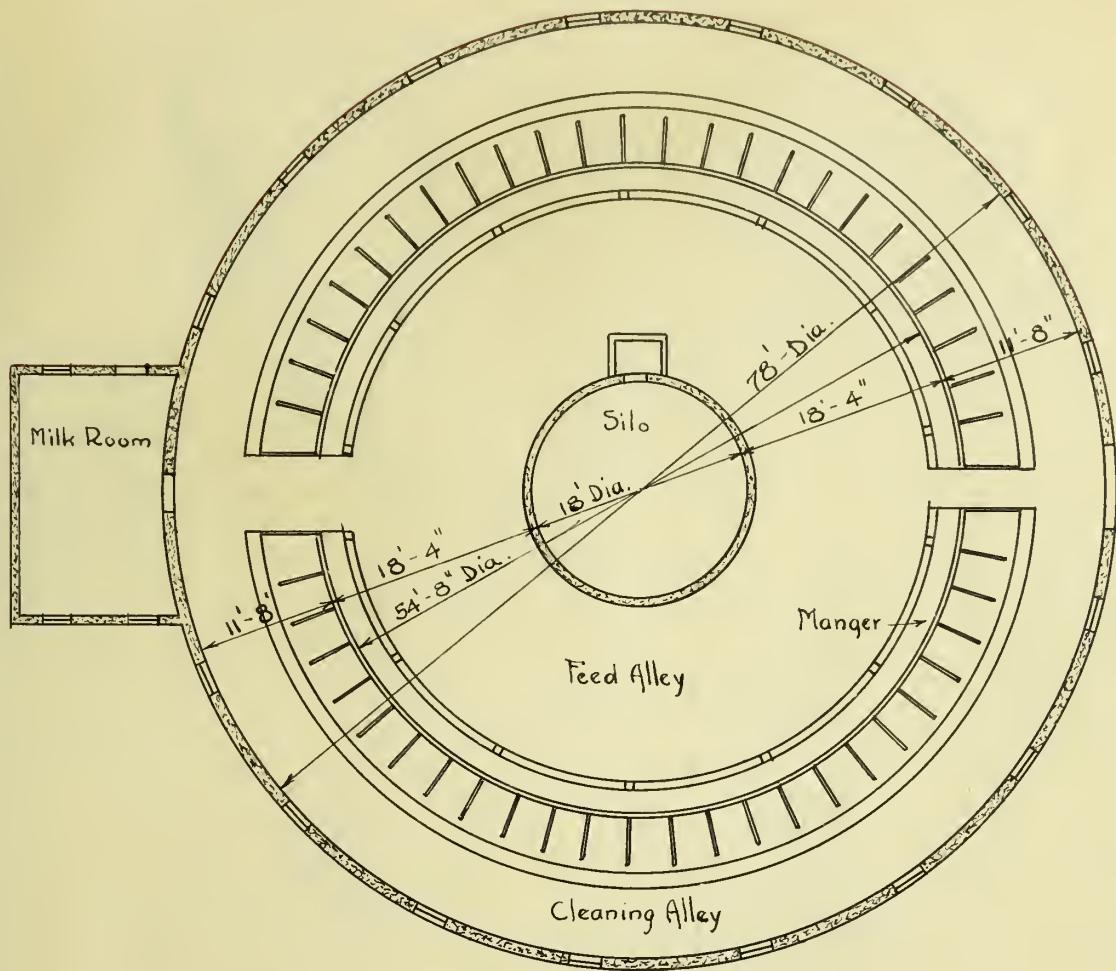


Table V.

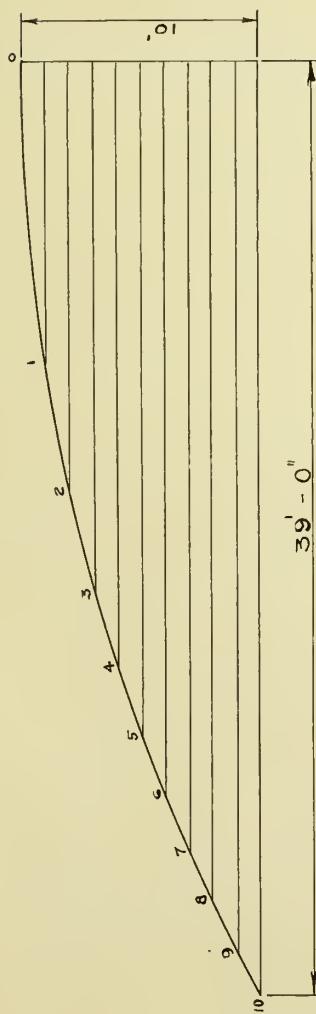
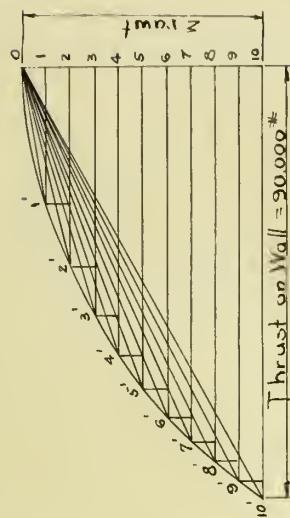
Point	Thick. Shell	S Length	Arc S x T	Horiz. Thrust lbs.	Aver. Horiz. Thrust on Vert. Face of Voussoir lb.sq.ft.	Side lb.sq.in.
1	.35	12.91	4.52	26,100	5774	40.1
2	.374	5.27	1.97	12,000	6090	42.3
3	.386	3.93	1.52	9,000	5920	41.1
4	.397	3.68	1.46	8,400	4800	40.3
5	.408	3.04	1.24	7,050	5685	39.4
6	.415	2.75	1.14	6,300	5520	38.3
7	.421	2.57	1.08	5,700	5280	36.6
8	.426	2.38	1.01	5,250	5200	36.1
9	.431	2.24	.96	4,950	5150	35.7
10	.436	2.07	.90	4,500	5000	34.7

Thrust on Wall = 90,000 lb.









STRESS DIAGRAM  
FOR  
REINFORCED CONCRETE DOME





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